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Simulation Study for Parametric EWMA and NPWEWPA-SR Control Charts Against Non-Normality Assumptions

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ABSTRACT

Common control chart types such as EWMA require assumptions to have valid information. A simulation was conducted to compare IC robustness and OOC performance for parametric EWMA and NPEWMA-SR control charts in the presence of a violation of symmetrical assumption. Monte Carlo simulation study held scale parameters with various shape parameters in Weibull distribution. It was found parametric EWMA and NPEWMA-SR control charts were unsuitable for applying asymmetrical distribution due to weak IC robustness and frequent false alarm. Although EWMA-$\bar{X}$ The control chart showed a most stable OOC performance; the weak IC robustness made the control chart unacceptable. Whereas, NPEWMA-SR control chart lost the ability in small shift detection when symmetrical assumption violated. Moreover, two different weightage of current sample for both parametric EWMA and NPEWMA-SR control charts were also investigated. The results showed that weightage of current sample for both parametric EWMA and NPEWMA-SR control charts did not affect the ARL value trend in different skewness of Weibull distribution.

Keywords: EWMA; control chart; NPEWMA-SR; skewness; robustness; non-parametric

INTRODUCTION

Weibull distribution is a distribution with characteristics of many different types of distributions. This fact makes it famous among engineers and quality practitioners and is widely used in many fields such as survival analysis, various industrial areas and quality control. Weibull distribution contains two parameters: scale parameter, λ and shape parameter, k. The probability density function of Weibull distribution is written as follows:

$$f(x;\lambda,k) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right) e^{-\left(\frac{x}{\lambda}\right)^k} & x \geq 0 \\ 0 & x < 0. \end{cases} \quad (1)$$

In the Equation (1), the k value is set to obtain the skewness coefficient value from 0.1 to 9.0 with fixed λ = 1 [1]. The value of skewness is inversely proportional to the shape

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parameter, k and the value of skewness coefficient is calculated by the following expression (Equation (2)):

$$\mu = E(X) = \lambda\Gamma\left(1 + \frac{1}{k}\right)$$

$$\sigma^2 = \lambda^2\left[\Gamma\left(1 + \frac{2}{k}\right) - \left(\Gamma\left(1 + \frac{1}{k}\right)\right)^2\right]$$

$$Skewness = \frac{\Gamma\left(1 + \frac{3}{k}\right)\lambda^3 - 3\mu\sigma^2 - \mu^3}{\sigma^3} \quad (2)$$

Since the NPEWMA-SR control chart is modified by adding concept of Wilcoxon Signed-Rank statistic, the properties of the control chart is related to Wilcoxon Signed-Rank statistic. Consequently, brief information about Wilcoxon Signed-Rank statistic is introduced. The test is a non-parametric procedure as an alternative to the t-test statistic when comparing two related samples, matched samples, or a repeated measurements on a single sample [2]. To compare the performance between non-parametric and parametric statistics, asymptotic relative efficiency (ARE) is used, ([3][4]). ARE is an efficiency comparison measurement where ARE value represents the efficiency ratio between two statistic procedures or tests. [5] and [6] stated that the ARE of signed-rank test relative to t-test is 0.955, 1, 1.097 and 1.5 for the Normal, Uniform, Logistic and Laplace distributions, respectively. The ARE values above indicate signed-rank test is only slightly weaker than t-test in Normal distribution, and signed-rank test is much powerful than t-test in nonnormal distribution. Consequently, the non-parametric statistical test is widely used in many sectors due to only few underlying assumptions need to be fulfilled, such as the samples must come from continuous and symmetrical distribution. [7]–[9] have shown that the Wilcoxon Signed-Rank test is not robust against the symmetrical assumption.

This study investigates the robustness of in-control (IC) and out-of-control (OOC) performance for parametric EWMA and NPEWMA-SR control charts in violation of symmetrical assumption using simulation study. Many research have been conducted to study the robustness of various statistical test, such as [10]–[12] . Meanwhile, [13] have studied the application of permutation theory to derive robustness criteria for the details regarding a statistical test's robustness. They mentioned two criteria for a good statistical test: quick detection in change of specific factor and insensitivity to detect change in extraneous factor that not include in the test. The first criterion is the test's power, whereas the second criterion is the robustness of the test. In this paper, the robustness of each control charts is used.

METHODS

NPEWMA-SR control chart is a non-parametric control chart, where although it s relatively robust to the normality assumption, but the requirement of symmetrical distribution should not be violated. Hence, the impact of violation in symmetrical assumption to control charts is studied through a simulation study. The simulation study in this study mainly aims to learn the robustness of parametric EWMA and NPEWMA-SR control charts against the assymmetrical assumption.

The first step is choosing the design parameters with approximately the same performance for each control chart to avoid unsuitable comparisons. The control chart's design parameter is divided into two parts. The first part is chosen based on best combination of (L, λ) on $ARL_0 \approx 500$ and smallest ARL_1 in detecting δ =1.5 shift of in the process mean in simulation study of Normal distribution. The second part is to use the same λ value with λ=0.10 for all control charts and choose the combination of $ARL_0 \approx 500$ in simulation study of Normal distribution. The design parameters in the first part are EWMA (L=2.998, λ=0.25, n=1), EWMA-$\bar{X}$ (L=3.1, λ=0.25, n=10) and NPEWMA-SR (L=2.905, λ=0.20, n=10**)**. Whereas the second part are EWMA (L=2.814, λ=0.10, n=1), EWMA-$\bar{X}$ (L=2.815, λ=0.10, n=10) and NPEWMA-SR (L=2.794, λ=0.10, n=10). The subgroup size of the NPEWMA-SR control chart is fixed at 10 as [14] suggested. [15] also mentioned that the minimum subgroup size needed to construct a traditional 3δ limits control chart in Wilcoxon Signed-Rank statistic. To avoid unfair comparison due to the difference in subgroup size between EWMA-$\bar{X}$ and NPEWMA-SR control charts, subgroup size of 10 is fixed for EWMA-$\bar{X}$ control chart.

The design parameters in the first and second parts of the control charts are used for testing the IC robustness and OOC performance. Seven different shape parameters each control chart in Weibull distribution (skewness level = 0.1, 0.5, 1.0, 2.0, 3.0, 4.0 and 5.0) and 8 levels of δ times standard deviation for shifting process mean (δ = 0, 0.25, 0.5, 0.75, 1, 1.5, 2 and 3).

IC Robustness

There are two options in choosing an acceptable ARL_0 value, which are either $ARL_0 \approx$ 370 or 500 ([16], [17]). In this simulation study, combinations of design parameters to obtain the $ARL_0 \approx 500$ are arbitrarily chosen since larger ARL_0 value indicates that there is less adjustment needed in a process without any shift in the process mean. Moreover, the robustness of the ARL_0 in symmetrical and asymmetrical distributions is compared among the control charts.

OOC Performance

Whereas ARL_1 value in the specific value of shift in the process mean between symmetrical and asymmetrical distributions are recorded to observe the OOC performance. Furthermore, the minimum sample required before the first OOC point in the NPEWMA-SR control chart is calculated by applying Equation 3. For example, when n=10, L=2.905, and λ=0.20, the control limits can be calculated based on Equation 3, where UCL/LCL= ±12.4596. Then, substitute the value for UCL/LCL into the second equation of Equation 3, minimum sample required before the first OOC point, i=1.1512 will be obtained. Since the first OOC point can only be an integer number, the NPEWMA-SR control chart can only signal the first out-of-control point on or beyond sample number 2.

$$\frac{UCL}{LCL} = \pm L \sqrt{\left(\frac{n(n+1)(2n+1)}{6}\right)\left(\frac{\lambda}{2-\lambda}\right)}$$
$$i \geq \frac{ln(1 - 2UCL/(n(n+1)))}{ln(1-\lambda)} \tag{3}$$

Simulation Algorithm

Performance of the IC robustness and OOC detection between EWMA, EWMA-$\bar{X}$, and NPEWMA-SR control charts are compared. Comparisons will be conducted based on

Weibull (λ, k) distributions with fixed scale parameter, λ=1 and varying shape parameter, k, and combined with varying process mean shift in δ times of standard deviation (δ =0, 0.25, 0.5, 0.75, 1, 1.5, 2 and 3). The shape parameter was increased to have the move for the Weibull distribution from symmetrical to become more asymmetrical distribution. The simulation steps are show as follows:

Step 1: Specify the design parameter (λ, L) and subgroup size, n for parametric EWMA and NPEWMA-SR control charts,

Step 2: Apply the specific design parametric for both parametric EWMA and NPEWMA-SR control charts in Normal distribution and Weibull distribution,

Step 3: Generate 4000 observations for Normal (0,1) and Weibull (λ,k) with λ=1 and varying k,

Step 4: Calculate the steady-state control limits using parametric EWMA and NPEWMA-SR control charts,

Step 5: Record the number of subgroups needed until 1st OOC point being detected in each control chart,

Step 6: Repeat steps 1-5 for 2000 times, and

Step 7: Use proc univariate of SAS 9.4 to obtain the ARL_0 and ARL_1 for each control chart.

RESULTS AND DISCUSSION

The ARL tables were displayed for EWMA, EWMA-$\bar{X}$ and NPEWMA-SR control charts under Normal and Weibull distributions and compare the IC robustness and OOC performance among the control charts.

Table 1. Bias of Parameter Estimates of LD, MS and MI Method

δ	Control Chart	*L*					
		2.6	**2.7**	**2.8**	**2.9**	**3.0**	**3.1**
0.00	EWMA	156.347	208.281	272.719	388.237	482.594	673.542
	EWMA-$\bar{X}$	135.701	172.306	227.804	293.446	391.079	523.033
	NPEWMA-SR	202.332	271.528	350.138	484.479	688.299	965.720
0.25	EWMA	71.952	89.679	112.613	139.790	166.144	216.106
	EWMA-$\bar{X}$	11.195	12.257	13.519	15.191	16.573	17.863
	NPEWMA-SR	13.695	15.279	16.456	18.766	20.852	23.516
0.50	EWMA	26.525	30.324	36.436	40.540	49.197	56.869
	EWMA-$\bar{X}$	3.859	4.206	4.371	4.619	4.826	5.176
	NPEWMA-SR	5.019	5.354	5.515	5.906	6.279	6.565
0.75	EWMA	13.488	14.095	16.228	17.638	20.325	22.783
	EWMA-$\bar{X}$	2.449	2.520	2.615	2.712	2.812	2.954
	NPEWMA-SR	3.31	3.479	3.595	3.748	3.977	4.099
1.00	EWMA	7.991	8.814	9.564	10.159	11.392	12.218
	EWMA-$\bar{X}$	1.825	1.914	1.966	2.005	2.086	2.143
	NPEWMA-SR	2.652	2.755	2.909	3.061	3.191	3.292
1.50	EWMA	3.585	4.608	4.941	5.175	5.494	5.846
	EWMA-$\bar{X}$	1.183	1.203	1.261	1.303	1.357	1.433
	NPEWMA-SR	2.099	2.154	2.254	2.433	2.765	3.004

δ	Control Chart	*L*					
		2.6	**2.7**	**2.8**	**2.9**	**3.0**	**3.1**
	EWMA	3.041	3.199	3.318	3.464	3.603	3.738
2.00	EWMA-$\bar{X}$	1.007	1.012	1.015	1.021	1.026	1.045
	NPEWMA-SR	2.002	2.006	2.024	2.082	2.367	3.000
	EWMA	1.970	2.056	2.094	2.182	2.237	2.340
3.00	EWMA-$\bar{X}$	1.000	1.000	1.000	1.000	1.000	1.000
	NPEWMA-SR	2.000	2.000	2.000	2.000	2.026	3.000

Note: ARL_1 values for NPEWMA-SR control chart converge to 2.000 for L=2.6 until 3.0 and converge to 3.000 for L=3.1 due to restriction of Equation 3.

Under Normal (0,1) distribution for EWMA, EWMA-$\bar{X}$ and NPEWMA-SR control charts with fixed λ value and varying L, the ARL value increases as the L increases from 2.6 to 3.1 and it showed decreasing trend when δ gets larger. Meanwhile, the OOC performance between these three control charts are also investigated. The first step is to set a design parameter (L, λ) for each control chart. In order to set the design parameters, EMWA (L=3.0, λ=0.25, n=1) with ARL_0=482.594, EWMA-$\bar{X}$ (L=3.1, λ=0.25, n=10) with ARL_0=523.033 and NPEWMA-SR (L=2.9, λ=0.20, n=10) control charts with ARL_0=484.479 were chosen for the comparison since the $ARL_0 \approx 482.594$. It was found that for the detection of OOC for δ = 0.25 to 3.0, the EWMA-$\bar{X}$ control chart has smaller ARL_1 value than both EWMA and NPEWMA-SR (Figure 1). More specifically, the OOC performance of NPEWMA-SR control chart is comparable to the EWMA control chart (Table 1).

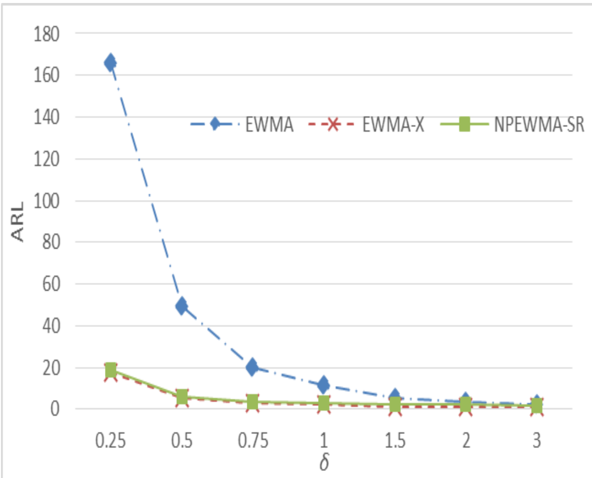


Figure 1. ARL_1 Values under Normal (0,1) Distribution for EMWA, EWMA-$\bar{X}$, and NPEWMA Control Charts

Table 2 shows that the ARL values increase as L gets larger, whereas ARL values decrease as the δ increases for all the control charts. Besides that, the design parameters for these control charts were chosen as EWMA (L=2.9, n=1), EWMA-$\bar{X}$ (L=2.9, n=10) and NPEWMA (L=2.8, n=10) control charts with fixed λ=0.10 because the ARL_0 is approximately equal to 500. By comparing ARL_1 values on the Table 2 (and Figure 2), it showed that the EWMA-$\bar{X}$ control charts have better OOC performance than EWMA and NPEWMA-SR control charts. Since the ARL_1 values are not much different for EWMA-$\bar{X}$ and NPEWMA-SR control charts indicated that the OOC performance is comparable between both control charts. Furthermore, the results also showed that different combinations of (L,λ) would not affect the ARL trend of the control chart when δ gets larger in Normal distribution.

Table 2. ARL Values under Normal (0,1) Distribution for Varying L and fixed λ=0.10 in EWMA with n=1, Both EWMA-$\bar{X}$ and NPEWMA-SR Control Charts with n=10

δ	Control Chart	L				
		2.7	**2.8**	**2.9**	**3.0**	**3.1**
0.00	EWMA	358.075	485.506	626.114	830.880	1094.799
	EWMA-$\bar{X}$	306.306	388.340	532.398	641.375	884.654
	NPEWMA-SR	381.123	523.500	686.643	888.998	1203.414
0.25	EWMA	85.089	109.547	119.933	143.165	172.402
	EWMA-$\bar{X}$	12.823	13.876	14.752	15.679	16.532
	NPEWMA-SR	15.068	16.459	17.173	19.360	20.126
0.50	EWMA	27.913	29.994	35.484	37.450	40.827
	EWMA-$\bar{X}$	5.250	5.450	5.760	5.950	6.187
	NPEWMA-SR	6.306	6.513	6.811	7.186	7.539
0.75	EWMA	14.698	15.728	16.700	17.833	19.092
	EWMA-$\bar{X}$	3.383	3.518	3.622	3.819	3.919
	NPEWMA-SR	4.283	4.428	4.643	4.838	5.008
1.00	EWMA	9.869	10.360	10.805	11.471	12.128
	EWMA-$\bar{X}$	2.553	2.637	2.747	2.814	2.912
	NPEWMA-SR	3.529	3.645	3.788	3.954	4.109
1.50	EWMA	5.797	6.018	6.354	3.534	6.871
	EWMA-$\bar{X}$	1.914	1.952	1.991	2.012	2.036
	NPEWMA-SR	3.013	3.034	3.080	3.164	3.330
2.00	EWMA	4.195	4.283	4.475	4.655	4.791
	EWMA-$\bar{X}$	1.386	1.470	1.555	1.640	1.716
	NPEWMA-SR	3.000	3.000	3.001	3.005	3.023
3.00	EWMA	2.768	2.835	2.971	3.050	3.150
	EWMA-$\bar{X}$	1.001	1.002	1.005	1.007	1.204
	NPEWMA-SR	3.000	3.000	3.000	3.000	3.000

Note: ARL_1 values for NPEWMA-SR control chart converge to 3.000 due to the restriction of Equation 3.

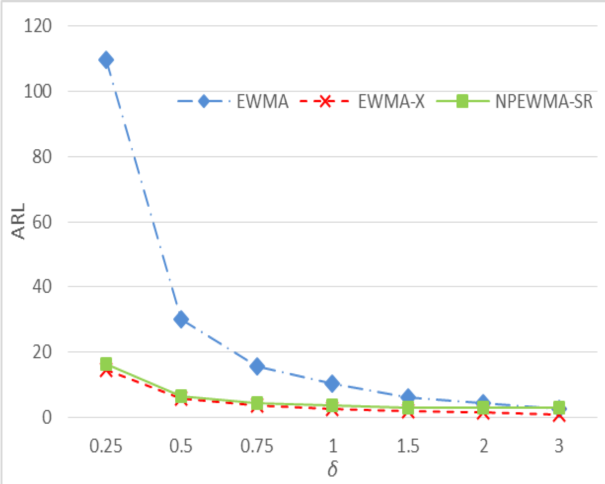


Figure 2. ARL_1 Values under Normal (0,1) Distribution by Fixing λ=0.10 for EWMA, EWMA-$\bar{X}$ and NPEWMA Control Charts

By comparing the IC robustness for each control chart, the ARL_0 value of the control charts showed decreasing trend when the distribution goes to more-asymmetrical (Table 3 and Figure 3 (a)). The results also indicated that the IC robustness of the control charts are poor when the symmetrical assumption is violated. The ARL_0 values of EWMA-$\bar{X}$ control chart were larger than both EWMA and NPEWMA-SR control charts. These indicate that the EWMA-$\bar{X}$ control chart more robust for the IC in violation of symmetrical assumption than EWMA and NPEWMA-SR control charts.

Figure 3 (b) compared the control charts at δ = 0.25. The ARL1 value of EWMA control chart gets smaller until the shape parameter of Weibull distribution is equal to 0.6478 and slightly increases as the distribution becomes more asymmetric. However, the NPEWMA-SR shows an increasing trend for ARL1 value until the shape parameter equals 0.6478, and it decreases when the distribution becomes more asymmetric. In this study, it was found that the EWMA-$\bar{X}$ control chart is the only control chart with few differences in ARL1 value when the distribution becomes more asymmetrical. It indicated that the violation in symmetrical assumption gives a bigger effect on small shift detection for NPEWMA-SR control chart than both parametric EWMA control charts. On the other hand, EWMA-$\bar{X}$ control chart was the most stable control chart, which still able to detect slight shift in process mean. Besides that, it was found that the EWMA-$\bar{X}$ control chart is the only OOC robust control chart for violation in symmetrical assumption since it shows non-fluctuated ARL_1 values compared to EMWA and NPEWMA-SR control charts.

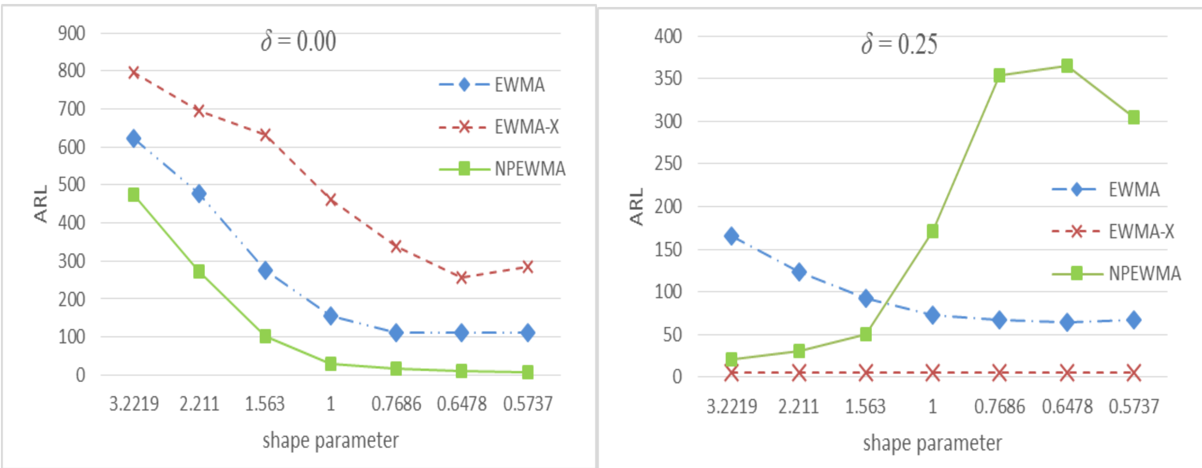
Unfortunately, the EWMA-$\bar{X}$ control chart is not robust for the IC in the violation of the symmetrical assumption because the ARL_0 value decreases when the distribution goes to asymmetrical. In violation of symmetrical assumption, NPEWMA-SR control chart loss its ability to detect small shift in process mean. However, it shown a comparable ARL_1 value for OOC performance in δ = 0.5 and above. In short, these three control charts are unsuitable to apply in asymmetrical distribution, since false alarm will happen frequently.

Table 3. ARL Values under Weibull (λ,k) Distribution with Fixed λ=1 and Varying k Value for EWMA, EWMA-$\bar{X}$, and NPEWMA-SR Control Charts

δ	Control Chart	k						
		3.2219	**2.2110**	**1.5630**	**1.0000**	**0.7686**	**0.6478**	**0.5737**
0.00	EWMA	624.222	476.965	275.405	155.720	110.789	109.962	112.492
	EWMA-$\bar{X}$	796.000	696.232	631.366	463.219	337.722	256.248	284.950

	NPEWMA-SR	474.689	273.679	101.240	28.991	15.723	11.421	8.885
	EWMA	165.230	123.691	93.095	73.115	67.368	64.953	67.510
0.25	EWMA-$\bar{X}$	20.464	20.086	19.763	20.490	20.146	19.619	20.830
	NPEWMA-SR	20.863	30.738	50.424	171.113	353.713	365.399	304.932
	EWMA	47.084	41.501	39.492	36.057	36.105	38.594	40.912
0.50	EWMA-$\bar{X}$	5.336	5.356	5.351	5.518	5.545	5.682	5.587
	NPEWMA-SR	6.116	6.571	7.259	7.453	6.637	4.901	3.365
	EWMA	19.632	19.643	19.894	20.134	21.325	23.804	25.964
0.75	EWMA-$\bar{X}$	3.064	3.059	3.053	3.053	3.044	3.085	3.100
	NPEWMA-SR	3.880	3.855	3.775	3.296	2.144	2.000	2.000
	EWMA	10.903	11.452	11.899	12.476	13.075	14.529	16.211
1.00	EWMA-$\bar{X}$	2.217	2.206	2.210	2.186	2.193	2.205	2.190
	NPEWMA-SR	3.096	3.020	2.906	2.000	2.000	2.000	2.000
	EWMA	5.583	5.738	5.766	5.896	6.333	6.317	6.725
1.50	EWMA-$\bar{X}$	1.469	1.490	1.487	1.513	1.527	1.546	1.567
	NPEWMA-SR	2.461	2.206	2.002	2.000	2.000	2.000	2.000
	EWMA	3.604	3.708	3.707	3.7525	3.765	3.743	3.727
2.00	EWMA-$\bar{X}$	1.056	1.050	1.033	1.029	1.013	1.003	1.000
	NPEWMA-SR	2.041	2.000	2.000	2.000	2.000	2.000	2.000
	EWMA	2.274	2.235	2.243	2.256	2.257	2.247	2.232
3.00	EWMA-$\bar{X}$	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	NPEWMA-SR	2.000	2.000	2.000	2.000	2.000	2.000	2.000

Note: ARL_1 values for NPEWMA-SR control chart converge to 2.000 due to the restriction of Equation 3.



(a) (b)

Figure 3. ARL Values for EWMA, EWMA-$\bar{X}$), and NPEWMA-SR Control Chart by Holding Level of Shift in Weibull Distribution at λ=1 and Varying k: a) at a) δ = 0.00, b) δ = 0.25

CONCLUSIONS

The simulation study has shown that parametric EWMA and non-parametric EWMA control charts are adversely affected by symmetrical assumption violation. In symmetrical Weibull distribution, both control charts had an acceptable ARL_0 value and OOC performance, which mean no frequent false alarm and fast detection in small shift of process mean. Unfortunately, both control charts were unsuitable for asymmetrical distribution due to unacceptable ARL_0 value. Comparison among the control charts in symmetrical Weibull distribution showed that NPEWMA-SR control chart has a better small shift detection performance and comparable ARL_0 value. In short, NPEWMA-SR control chart was one of the suitable methods to apply in nonnormal symmetrical distribution compared to parametric EWMA control chart.

In future work, modify parametric EWMA and NPEWMA-SR control charts by using the skewness corrective method to apply in asymmetrical distribution. Since the violation in symmetrical assumption will cause the non-parametric control chart to become unviable, a new non-parametric control chart with strong robustness in asymmetrical distribution will be considered for future study.

REFERENCES

[1] A. Pongpullponsak, W. Suracherkeiti, and R. Intaramo, "The Comparison of Efficiency of Control Chart by Weighted Variance Method, Scaled Weighted Variance Method, Empirical Quantiles Method and Extreme-value Theory for Skewed Populations," *Thailand Statistician*, vol. 5, pp. 1–23, 2007.

[2] I. C. A. Oyeka and G. U. Ebuh, "Modified Wilcoxon signed-rank test," *Open J Stat*, vol. 2, no. 2, pp. 172–176, 2012.

[3] N. Kumar and M. Goyal, "A general class of non parametric tests for comparing scale parameters," *Communications in Statistics-Theory and Methods*, vol. 47, no. 24, pp. 5956–5972, 2018.

[4] R. Jiang, W.-M. Qian, and Z.-G. Zhou, "Weighted composite quantile regression for partially linear varying coefficient models," *Communications in Statistics-Theory and Methods*, vol. 47, no. 16, pp. 3987–4005, 2018.

[5] F. S. Nahm, "Nonparametric statistical tests for the continuous data: the basic concept and the practical use," *Korean J Anesthesiol*, vol. 69, no. 1, pp. 8–14, 2016.

[6] J. D. Gibbons and S. Chakraborti, *Nonparametric statistical inference*. CRC press, 2020.

[7] P. Chavan and R. V Kulkarni, "Role of non-parametric test in management & social science research," *Quest International Multidisciplinary Research Journal*, vol. 6, no. 9, pp. 38–52, 2017.

[8] S. Datta, J. Nevalainen, and H. Oja, "A general class of signed-rank tests for clustered data when the cluster size is potentially informative," *J Nonparametr Stat*, vol. 24, no. 3, pp. 797–808, 2012.

[9] N. A. Ahad, S. S. S. Yahaya, Z. MdYusof, S. Abdullah, and L. Y. Fung, "Performance of the modified Wilcoxon signed rank test," in *AIP Conference Proceedings*, American Institute of Physics, 2014, pp. 690–694.

[10] J. M. Mahachie John, F. Van Lishout, E. S. Gusareva, and K. Van Steen, "A robustness study of parametric and non-parametric tests in model-based multifactor dimensionality reduction for epistasis detection," *BioData Min*, vol. 6, no. 1, pp. 1–17, 2013.

[11] E. Neumayer and T. Plümper, *Robustness tests for quantitative research*. Cambridge University Press, 2017.
[12] R. A. Maronna, R. D. Martin, V. J. Yohai, and M. Salibián-Barrera, *Robust statistics: theory and methods (with R)*. John Wiley & Sons, 2019.
[13] G. E. P. Box and S. L. Andersen, "Permutation theory in the derivation of robust criteria and the study of departures from assumption," *J R Stat Soc Series B Stat Methodol*, vol. 17, no. 1, pp. 1–26, 1955.
[14] N. Das, "A comparison study of three non-parametric control charts to detect shift in location parameters," *The International Journal of Advanced Manufacturing Technology*, vol. 41, pp. 799–807, 2009.
[15] Z. Abbas, H. Z. Nazir, M. Abid, N. Akhtar, and M. Riaz, "Enhanced nonparametric control charts under simple and ranked set sampling schemes," *Transactions of the Institute of Measurement and Control*, vol. 42, no. 14, pp. 2744–2759, 2020.
[16] I. S. Triantafyllou, "Nonparametric control charts based on order statistics: Some advances," *Communications in Statistics-Simulation and Computation*, vol. 47, no. 9, pp. 2684–2702, 2018.
[17] M. Noor-ul-Amin and S. Noor, "An adaptive EWMA control chart for monitoring the process mean in Bayesian theory under different loss functions," *Qual Reliab Eng Int*, vol. 37, no. 2, pp. 804–819, 2021.